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Commercial Building Indoor Air Quality

An Introduction to the Problem

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Abstract

This paper provides a background on the issue of indoor air quality. It includes a discussion of the financial, technical, legal, insurance and health-related aspects of unacceptable indoor air quality (IAQ). It discusses the roles of ventilation system performance, pollutant sources and human responses in determining acceptable indoor air quality as they relate to comfort, health and chronic illness. Finally, it discusses some issues confronting those who seek to formulate and implement policies to improve IAQ.

• Introduction

More than 3.3 billion square feet of new commercial buildings were constructed from 1988 to 1998. A 170% increase in commercial building stock is anticipated by the year 2030. That stock is expected to have a lifetime of 50 to 100 years. All these buildings must provide an acceptable indoor environment to support the productivity and well-being of the work force.

Building codes play a role in supporting the welfare of the community. They protect life, health and safety, and also protect the investments made by bankers, insurance companies, businesses and individuals. Finally, building codes promote economic development by protecting the value of the built environment. Building codes are one tool that policy makers can use to address the financial, legal, insurance and health-related aspects of unacceptable indoor air quality.

The process of designing, constructing, starting up, controlling and maintaining building systems is very complex. If done properly, the final product operates efficiently at reasonable cost, delivering comfort, safety and a healthy environment. If any part of this process breaks down, the product fails to deliver the benefits. The health-related and lost worker productivity costs from office environments amount to tens of billions of dollars per year for U.S. businesses (Levin, 1994). (See Appendix C with calculations of costs for office workers.) Additional energy costs of $22 to $45 billion (Davis, 1999) are incurred annually to operate buildings, due to these *broken* systems. One key to managing the complex process of designing and efficiently operating buildings in the future lies in the ability to manage information, deliver it to the proper audience and use it effectively for building design and operation. Building codes and other building regulations can play a constructive role in this process and effectively promote building ventilation performance that will efficiently and economically achieve good indoor air quality.

• Background

The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) defines *acceptable indoor air quality* as “air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.” (ASHRAE Standard 62-1999)

The notion that a substantial majority of the occupants do not express dissatisfaction comes directly from a tradition of thermal comfort research and ASHRAE’s thermal comfort Standard 55. Ordinarily, some fraction of building occupants (or laboratory study subjects) would like the air warmer or colder. Studies show that it is virtually impossible to have less than about 7% (deDear and Brager, 1998) of the occupants express dissatisfaction with the thermal environment, and in most cases it is more than 12% (*op cit*). As a practical goal, then, a maximum number of occupants expressing dissatisfaction with the thermal environment is set at 20%, or stated in the

positive form, no less than 80% of the occupants should be satisfied with the thermal environment. The *optimum* thermal environment is considered to be one in which half of the occupants request a warmer environment and half request a cooler environment. Historically, heating, ventilating, and air-conditioning systems were designed for thermal environmental control. Air quality was usually incidental, but if not, it was addressed simply by injecting some amount of outdoor air into the ventilation supply. The goal was to do this at the least first cost and the least operating cost. The amount of outdoor air required was always determined on the basis of odor studies or control of carbon dioxide (CO_2) concentrations. The earliest standards specified that CO_2 concentrations should not exceed certain minimum levels. Since those early standards, a rather wide range of ventilation standards has been adopted (see Appendix B). Ultimately, the amount of outdoor air required depends on numerous factors including the quality of the outdoor air, the type and strength of sources of contaminants inside the building, the occupant activities and the susceptibility of the occupant population.

The indoor air quality problems that draw our attention today began emerging in Europe and North America soon after the energy crisis precipitated by the Arab oil embargo of 1973. Recognition of these problems led to understanding that ventilation systems must address *pollution loads* as well as thermal loads. Gradually, more and more practitioners have agreed on the need for outdoor air to dilute indoor air contaminants and the need for both control of pollution sources and removal of point source pollution by direct exhaust to the outdoors.

• Impacts of Unacceptable Indoor Air Quality

Good or *acceptable* IAQ depends strongly on who must accept it. There are significant differences among the needs and perspectives of building owners, building occupants and public health organizations. Some of these are shown in Table 1.

Table 1 - Three Perspectives on Acceptable IAQ

Building Owners	No complaints, no tenant requirements for ventilation, no tenant polluting activities
US Environmental Protection (EPA) / Public Health Perspective	Minimizes exposure to toxics, irritants; no adverse health effects, no comfort complaints
Building Occupants	Clean, dry, well ventilated; thermally comfortable, no unfamiliar or objectionable odors.

Unacceptable IAQ has been found to affect occupant health, leading to illness and even death. Airborne infectious agents, such as the bacteria Tuberculosis and Legionnaire's Disease, cause infection as the result of inhaling the organism. Thus, control of indoor air quality is critical to protecting building occupants from such infections. Asthmatic and allergic reactions have many causes, including exposure to gases, pollen, particulate matter and microorganisms. Health effects of indoor pollution include the following:

- Infectious disease: flu, cold, pneumonia (Tuberculosis, Legionnaire's Disease, Pontiac Fever);
- Cancer, other genetic toxicity, teratogenicity (ecotoxicity);
- Asthma and allergy;
- Central nervous system (CNS), skin, gastrointestinal (GI), respiratory, circulatory, musculoskeletal and other systemic effects; and,

- Sick Building Syndrome (SBS) – commonly defined as any of several symptoms that appear associated with occupancy of a particular building but not clinically determined to be associated with a specific cause.

Unacceptable indoor air quality also affects the ability of employees to properly perform their jobs . This effect ranges from impacts on long-term job performance to short-term absence, and to distractions and discomforts that impair cognitive thinking. While it is hard to make a case directly from available evidence, much indirect evidence suggests that poor indoor air quality raises the cost of the U.S. workforce. Such indirect evidence from various studies includes death, job injury, asthma, illness, doctor visits, days absent, task performance and reduced attention span.

One study placed the annual cost of IAQ problems in U.S. buildings between $10 Billion and $100 Billion (Fisk and Rosenfeld, 1998). These amounts are comprised of direct costs of health care, lost work time and lost worker productivity, lost rents and lost learning or commercial opportunities. Table 2 depicts the magnitude of the potential economic benefits of improved IAQ associated with these cost estimates.

Table 2 - Estimated potential productivity gains from improvements in indoor environments (Fisk and Rosenfeld, 1998)

Source of Productivity Gain	Strength of Evidence	US Annual Savings or Productivity Gain (1993 $US)
Respiratory disease	Strong	$6 - $19 billion
Allergies and asthma	Moderate to Strong	$1 - $4 billion
Sick building syndrome symptoms	Moderate to Strong	$10 - $20 billion
Worker performance	Moderate to Strong	$12 - $125 billion
Total Range		$29 - $168 billion
Geometric mean		$70 billion

IAQ problems and the resulting illnesses and economic damages also can have legal and financial implications for all parties, including designers, builders, product manufacturers, building owners, employers, and occupants. Insurance and lending institutions are becoming increasingly involved in IAQ issues. Plaintiffs who were building occupants, employers, or owners have brought lawsuits for millions of dollars against designers, owners, manufacturers and contractors. Workers compensation claims by employees against their employers are widespread, although more commonly these involve public rather than private sector buildings. Poor indoor air quality has many such impacts, as described in Table 3.

Table 3 - Representative Impacts of Indoor Air Quality Problems

Target of Impact	*Potential Effects*
Designers, builders	Legal expenses, judgments and settlements
Product manufacturers	Damage to reputation and sales, legal expenses, settlements and judgments
Building owners	Lost tenants time and revenue,
	Expense of repairs
	Legal expenses, judgments and settlements
Employers	Lost productivity and revenue
	Payroll costs of absenteeism
	Deteriorating institutional environment
	Workers compensation claims
	Damage to public image or reputation
Building occupants	Health effects, illness, lost work time
	Discomfort, dissatisfaction, irritation
Building equipment	Deterioration, material damage
	Malfunction from fouling
	Breakdown
	Destruction from electrical arcing
Building fabric	Deterioration
	Soiling
	Increased maintenance costs

Investigations of problem buildings have provided valuable information about the sources and causes of poor IAQ. While he was at Honeywell, Dr. James Woods and his colleagues investigated over thirty problem buildings previously resistant to accurate diagnosis and remediation. Summarized in Table 4 are his findings of the type and frequency of *environmental stressors* in these buildings.

Table 4 - Types of Predominant Environmental Stressors for Indoor Air Quality Problems (Woods, 1988)

Type of Environmental Stressor	*Frequency (%)*
Chemical and Particulate Contaminants	75
with odor discomfort	70
Thermal discomfort	55
Microbiological contaminants	45
Non-thermal humidity problems (with eye irritation and mold growth from low- and high-relative humidity, respectively)	30

• Technical Issues that Contribute to Unacceptable Indoor Air Quality

Many different factors contribute to indoor air quality problems. Table 5 presents a list of some of the major factors that have been shown or are believed to affect IAQ to a significant degree.

Table 5 - Elements of a Building that Affect IAQ

Operation and maintenance of the building	Ventilation and comfort performance standards
	Ventilation system operational routines and schedules
	Housekeeping and cleaning
	Equipment maintenance, operator training
Occupants of the building and their activities	Occupant activities – occupational, educational, recreational, domestic
	Metabolism – activity and body characteristic dependent
	Personal hygiene – bathing, dental care, toilet use
	Occupant health status
Building contents	Equipment – HVAC, elevators
	Materials – emissions from building products and the materials used to clean, maintain, and resurface them
	Furnishings
	Appliances – cooking, office work
Outdoor environment	Climate, moisture
	Ambient air quality – particles and gases from combustion, industrial processes, plant metabolism (pollen, fungal spores, bacteria), human activities
	Soil – dust particles, pesticides, bacteria
	Water – radon, organic chemicals including solvents, pesticides, by-products of treatment process chemical reactions
Building fabric	Envelope – material emissions, infiltration, water intrusion
	Structure
	Floors and partitions

Following are some of the key technical areas that are achieving focus. These range chronologically from design through building operation, involving a variety of disciplines in the building life-cycle.

- Outdoor air intake and delivery;
- Design and operation of the HVAC system to maintain comfort;
- Source control of indoor air pollutants; and,
- Building performance integration and verification.

Outdoor air intake and delivery to occupied spaces

Outdoor air quality and quantity and its delivery to spaces within the building, including the breathing zones of occupants, are critical to achieving good IAQ. Occupant activities and other building contents determine the ventilation air required for maintenance of good IAQ. Leakage in ductwork can be significant, as much as 50 % of supply air, based on preliminary results from an ongoing EPA study of commercial building air quality. Short-circuiting of supply air to the return air system can result in stagnant air in *dead zones* within an occupied space. Failure of systems to deliver the quantity of outdoor air specified in the design can be caused by poor damper control and operation or inadvertent closing of outdoor air intake dampers. Finally, since many, if not most, commercial building ventilation systems are used to provide cooling and sometimes heating, as well, it is important that the thermal control scheme be effectively integrated into a system that can meet outdoor air supply requirements under all thermal load conditions. The primary issues include the following:

- Intake of clean outdoor air or filtration and cleaning of poor quality outdoor air;
- Design of an effective ventilation supply and distribution system;
- Design of an effective thermal control scheme;
- Selection of efficient equipment and proper controls to implement the ventilation and thermal control design; and,
- Supply of adequate outdoor air in hot, humid climates without creating moisture problems or unacceptable costs for ventilation equipment and its operation.

Design and operation of the HVAC system to maintain comfort

Ventilation systems are involved in maintaining thermal comfort. Many IAQ complaints are actually the result of failure to maintain appropriate thermal conditions in the occupied spaces. Following are some comfort maintenance issues to be addressed:

- Control by users permits a wider range of *acceptable* thermal conditions;
- User-controlled buildings have lower Sick Building Syndrome (SBS) symptom prevalence rates; and,
- Automated systems can take advantage of modern sensor and electronic technologies to optimize operations against a complex set of criteria and under dynamic conditions of weather and building use.

Source control of indoor air pollutants

Source control is far more cost-effective than dilution of contaminants by ventilation. Many public health officials and environmental pollution control authorities agree that source control is more effective and less costly than cleaning up pollution after it enters the environment. Generally, it is several times less costly to prevent pollution than to clean it up after it occurs, whether this is by stack emissions to ambient air, contamination of soil, surface water or groundwater, or pollution of indoor air.

Several trends suggest improvement of products intended for construction of building interiors, although considerably more can be done. Furthermore, it is not clear that products such as architectural coatings that satisfy ambient air quality protection laws and regulations (at the time of application?) are necessarily better for indoor air quality. Improvement of products in terms of emissions from materials and from maintenance and cleaning chemicals, as well as prevention of moisture intrusion or condensation and accumulation leading to microbial growth, could contribute to improved indoor air quality.

One of the most difficult problems to address is indoor air chemistry involving the reactions of ozone and other oxidants with indoor air chemicals including so-called *environmentally friendly* organic chemicals. These reactions produce more toxic or irritating compounds than those with which the oxidants react to produce them.

Building performance integration and verification

It is becoming more common to *commission* buildings after completion to verify that the building *as built* performs according to the design intent. Without some sort of verification, buildings typically do not deliver the outdoor air required by code or specified in the design. Over the life of the building operation, there must be continual verification (re-commissioning) since conditions change and affect building operations in subtle and undetected ways. The following activities have been effective in reducing indoor air quality problems:

- Thorough and adequate commissioning of buildings before occupancy;
- Ongoing monitoring and control of essential elements of the air quality control scheme; and
- Periodic verification of building environmental performance.

• Key Players Involved in IAQ

There are many players involved in understanding and improving indoor air quality. They range from health researchers to building owners and operators. All are trying to improve indoor air quality incrementally as the science and technology evolve and provide a better understanding of the problems. Some of the key players include standards developers, government, professional associations, industry, professionals, insurers and financiers.

Standards Developers

Many standards address various aspects of indoor air quality. There are no standards that are explicitly and exclusively directed at comprehensive indoor air quality. ASHRAE has established several standards and guidelines committees including *Ventilation for Acceptable Indoor Air Quality, Thermal Comfort for Human Occupancy, Criteria for Achieving Acceptable Indoor Environments* and others to develop standards for indoor environmental quality.

Standards often form the basis for code requirements. Building code requirements that address indoor air quality are typically found in the mechanical code. In some states, they are found in the energy code. The International Mechanical Code's Chapter 4 contains ventilation rates and other requirements for commercial and high-rise residential buildings. Appendix A of this paper contains a comprehensive list of standards relevant to IAQ.

Government

Government typically establishes regulations, funds research, conducts educational programs and provides investigative and technical assistance regarding reported IAQ problems. The regulatory role has been limited(?) to establishment of authority for development and enforcement of regulations, codes and standards. Government agencies provide small funding for IAQ research (~ $10 – $30 million per year). Funding is currently part of a major increase in the federal focus on asthma. There is also some related research to reduce energy consumption required to provide adequate IAQ. Finally, an indoor occupational health research agenda is being prepared by an ongoing project of the National Institute for Occupational Safety and Health (NIOSH) National Occupational Research Agenda (NORA) Indoor Environment Team. Educational programs include EPA's *Tools for Schools*. The *Tools for Schools* kit includes a training course, a web site and an information clearinghouse. Investigation by NIOSH, part of the U.S Centers for Disease Control (CDC), and by state agencies sometimes help identify building-specific problems. The United States Occupational Safety and Health Administration (OSHA) is charged with protecting worker health, but has insufficient staff and resources to be effective. Technical assistance, mostly from state governments, is very limited, except in the few states with significant IAQ programs.

Professional Associations

There are numerous professional associations representing designers, consultants, trade and industry associations and others whose work affects and is affected by indoor air quality issues. Some of these are the American Industrial Hygiene Association (AIHA), ASHRAE, American Society for Testing and Materials (ASTM), Building Owners and Managers Association (BOMA), National Association of Home Builders (NAHB), Sheet Metal and Air-Conditioning Contractors National Association (SMACNA), National Air Duct Cleaners Association (NADCA), Association of Air Balance Contractors (AABC), International Society of Indoor Air Quality and Climate (ISIAQ), American Institute of Architects (AIA), International Association of Plumbing and Mechanical Officials (IAPMO) and the International Code Council (ICC).

Industry

A number of manufacturers are involved in specific aspects of improving indoor air quality. Most focus within their narrow area of product or expertise to address one aspect of the IAQ problem. This makes it difficult for industry to provide a more holistic solution, as most businesses are not configured to effectively address problems at a system level.

Some of the key players and their area of involvement in improving indoor air quality include the following:

- Building product manufacturers are involved in reducing emission source strengths and removing some hazardous or noxious components;
- Air quality measurement device manufacturers have products designed for applications in HVAC control systems, investigations of problem buildings and evaluation of building performance during commissioning;
- Ventilation system equipment manufacturers are introducing devices for better control of outdoor air supply, reducing problems from duct moisture and improving duct acoustic and thermal insulation IAQ performance;
- Furnishing manufacturers are reducing emissions from their products including emissions of formaldehyde, VOCs, other odorants, irritants and toxins; and,

- Air cleaning equipment manufacturers have made improvements in filter performance without unacceptable pressure drop, improved characterization of filter performance over filter service life (ASHRAE Std 52.2) and developed a variety of products capable of capturing gaseous contaminants and particulate matter.

Professionals

Building design professionals increasingly are designing for good IAQ, helping owners and occupants understand IAQ issues and even helping to resolve problems. They are capable of addressing the problems at a systems level, and can integrate client, occupant and operational needs into a holistic solution for a particular building.

Consultants play a large role by advising building owners and occupants of problem buildings, investigating causes when appropriate and helping design professionals design for good IAQ by specifying *healthy* materials and designing effective ventilation systems. Consultants can be particularly beneficial when they offer design professionals access to a more in-depth set of resources, serving as a link between the research community and design professionals.

Researchers play an important role by characterizing indoor air quality and occupant responses, conducting studies to find associations between building design, construction, operation and maintenance practices with adverse occupant outcomes, investigating building physics and developing means to reduce emissions of contaminants or intrusion of moisture. Also, they are improving effective means to control contaminants through dilution and exhaust ventilation or through source control.

Insurers, Financiers

Insurance companies are experiencing increasing claims for workers compensation and law suits when employees or other building occupants are adversely affected by poor IAQ. Some of these lawsuits have been completed and settlements or jury awards upwards of ten million dollars have been reported. Most lawsuits are settled for undisclosed sums, but reported settlements range from tens of thousands to several million dollars.

Lenders are finding that in a weak real estate market, good IAQ can be important to highlight in marketing commercial real estate. At worst, lenders have learned that IAQ-related litigation can damage the marketability of a property.

• Building Codes and IAQ

Building codes traditionally begin with the design of a building. Three types of codes are in effect: building codes, fire codes, and occupational safety and health regulations. The various players in the design and construction processes interact with codes and occupational safety and health regulations that pertain to the occupancy of the building.

IAQ is not a simple issue. Efforts to ensure good IAQ through minimum code requirements can result in penalizing buildings where high quality design, construction, operation or maintenance are in place. Concomitantly, minimum code requirements may require too little to protect public health and safety in buildings where efforts tend to focus on avoiding any costs beyond absolute minimums. For example, increasing minimum ventilation rates to account for poor quality design, construction, operation or maintenance penalizes those who create high quality buildings. Lowering minimum ventilation rates to accommodate the humid southeastern U.S. climate results in under-ventilation where strong indoor pollutant sources are present.

Certain simple code requirements can work for some aspects of IAQ, but may be difficult to translate into enforceable code language. This often occurs with language intended to create performance-based requirements but actually requiring no more than design consideration of certain issues. For example, the existing ASHRAE ventilation standard urges designers to consider cleaning outdoor air when it does not meet Federal Clean Air Act (CAA) requirements. However, the ASHRAE committee responsible for the standard has interpreted this requirement as a non-mandatory aspect of the standard. Few commercial buildings actually contain equipment to filter or clean outdoor air pollutants including respirable particles or gaseous contaminants (such as ozone and carbon monoxide) regulated by the Clean Air Act. Yet over 80 million Americans live and work in areas where outdoor air quality violates the National Ambient Air Quality Standards (NAAQS) promulgated by EPA as required by the CAA.

Code requirements must work with other regulatory mechanisms to bring about good IAQ. In occupational settings, state and federal worker protection regulations will often be more important than the building code itself in achieving safe and healthy IAQ. For example, until the passage of an explicit California OSHA requirement that building ventilation systems be operated according to the design intent, there was no legal requirement that existing ventilation systems be operated! Consumer product requirements are necessary to reduce or eliminate many sources of indoor pollution in non-residential (and residential) occupancies. The U.S. Justice Department is currently prosecuting manufacturers of certain *air cleaners* for false claims. Among these products are ozone-generating devices authorities consider harmful to the health of building occupants and incapable of delivering promised benefits.

The ASHRAE SSPC62.1 committee is developing a standard that could be helpful, but the current draft requires only the bare minimum. For example, the draft proposes actually reducing ventilation rates in schools from 15 cubic feet per minute per person (cfm/p) of outdoor air supply to approximately 11 cfm/p. One of the rationales given by committee members supporting the change is that most schools are not meeting the current standard so lowering it might improve compliance. This rationale obviously has not a health or comfort basis. Much of the perceived need to reduce the rate has come from the southeastern United States, where high outdoor air humidity places an additional burden on ventilation systems and increases operating costs. Finding the lowest common denominator for the entire country requires compromises for the extreme climates that may not be appropriate for each other or for temperate climates. In temperate climates, during much of the year, increased outdoor air can be used at very little or no energy penalty. This is not true for extremely cold (northern) or extremely warm and humid (southeastern) climates.

There are too few organizations that advocate effectively for occupants in the IAQ standards and code writing process. Interested groups like the American Lung Association and labor unions generally do not have sufficient resources to sustain such activity.

There is much confusion about what is going on with ventilation rates. What we know and don't know about the relationship between ventilation rates and occupant health and comfort responses would fill many scientific and professional conferences of epidemiologists, toxicologists, engineers, building scientists, industrial hygienists and architects. There is an apparently strong correlation between decreased ventilation rates and the increased prevalence of SBS symptoms and perceptions of unacceptable IAQ. There is much less clarity about precisely where rates should be set in a regulatory framework -- including building codes.

More and more IAQ experts are focusing on the performance of the HVAC system to make sure the building delivers what is designed. Persily (1989) and others have documented the absence of a correlation among ventilation rates as measured and those designed or required by codes. Among enlightened professionals and building owners, commissioning has become more common practice to ensure delivery of designed ventilation, but it may be premature to require full HVAC commissioning in code documents.

Operation and maintenance of the HVAC system is ultimately the most critical factor of all. California adopted a worker protection regulation requiring HVAC system operation according to the design. In most jurisdictions, there are no explicit requirements regarding operation, and poor operational and maintenance practices are clearly responsible for many IAQ problems.

• Conclusion

This paper has introduced many topics that must be discussed and many issues that must be resolved before significant action can be taken on development of new building code requirements intended to improve IAQ and protect building occupants.

There is increasing commercial interest in IAQ. In some cases this results in products and services that enhance IAQ in buildings. However, because IAQ is the result of a complex set of factors, some solutions are overly simplistic and lead to sub-optimization. The search for *silver bullets* includes simple indicators of IAQ; both carbon dioxide and total volatile organic chemical (TVOC) concentrations have been abused as indicators of IAQ. Another type of *silver bullet* has been the air cleaner that purportedly removes everything. Both ozone generators and electrostatic filters have been marketed with exaggerated claims for their efficacy in improving IAQ. A susceptible and poorly educated market is ripe for abuse by clever or even poorly informed but well-meaning entrepreneurs.

This workshop on commercial building codes and indoor air quality is dedicated to increasing the awareness of code developers and policy makers of some of the issues that must be addressed and the state of the science involved in understanding these issues.

• References

ASHRAE, 1999. *ANSI/ASHRAE 62-1999*, *Ventilation for Acceptable Indoor Air Quality*

Davis, RG, 1999. "Building Commissioning Total Cost of Ownership", *In Proceedings of National Conference on Building Commissioning '99.,* Portland: Portland Energy Conservation, Inc. (PECI).

DeDear, R. and Brager, G., 1998. "Developing An Adaptive Model Of Thermal Comfort And Preference. ASHRAE Transactions 1998, Vol. 1.

Fisk, W.J. and AH Rosenfeld. 1998. "Potential Nationwide Improvements in Productivity and Health from Better Indoor Environments", *In Proceedings of ACEEE Summer Study '98*, vol. 8 85-97, Asilomar

Levin, H., 1994, Expert Testimony for the U. S. Department of Labor, on Proposed OSHA Indoor Air Quality Rule, (Federal Register April 5, 1994). September 22, 1994, Washington, DC

Persily, A., 1989. "Ventilation Rates in Office Buildings." In *IAQ 89 - The Human Equation: Health and Comfort*. Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc. pp. 128-136.

• APPENDIX A: STANDARDS AND GUIDELINES IMPORTANT FOR INDOOR AIR QUALITY

1. ACGIH, 1999. *Bioaerosols: Assessment and Control*. Cincinnati: American Conference of Governmental Industrial Hygienists. 313 pages.
2. ACGIH, 1999. *Guide to Occupational Exposure Values – 1999*. Cincinnati: American Conference of Governmental Industrial Hygienists, Inc.
3. ASHRAE, 1988. ANSI/ASHRAE 111-1988, *Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air-Conditioning, and Refrigeration Systems*. Atlanta: American Society of Heating, Ventilating, and Air-conditioning Engineers, Inc.
4. ASHRAE, 1992. *ANSI/ASHRAE 55-1992, Thermal Environmental Conditions for Human Occupancy*, Atlanta: American Society of Heating, Ventilating, and Air-conditioning Engineers, Inc.
5. ASHRAE, 1999. *ASHRAE 62-1999*, *Ventilation for Acceptable Indoor Air Quality*. Atlanta: American Society of Heating, Ventilating, and Air-conditioning Engineers, Inc.
6. ASHRAE, 1997. Draft Standard *62-1989R Public Review Draft*, *Ventilation for Acceptable Indoor Air Quality*. Atlanta: American Society of Heating, Ventilating, and Air-conditioning Engineers, Inc.
7. ASHRAE *Guideline 1-1996, The HVAC Commissioning Process*. Atlanta: American Society of Heating, Ventilating, and Air-conditioning Engineers, Inc.
8. ASHRAE *Guideline 4-1993, Preparation of Operating and Maintenance Documentation for Building Systems*. Atlanta: American Society of Heating, Ventilating, and Air-conditioning Engineers, Inc.
9. ASTM D 5116-97: "Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products." Volume 11.03 of the *ASTM Annual Book of Standards*. West Conshohocken, PA: American Society for Testing and Materials. (Can be downloaded from www.ASTM.org or purchased by phone from ASTM Publications, 610 832 9500)
10. ASTM D 6245-98, "Standard (formerly PS40) Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation," American Society for Testing and Materials, West Conshohocken, PA. (Can be downloaded from www.ASTM.org or purchased by phone from ASTM Publications, 610 832 9500)
11. ASTM D 5952-96. "Guide to investigating possible outbreaks of Legionellosis (Legionnaires Disease or Pontiac Fever) and concerns about related environmental contamination." American Society for Testing and Materials, West Conshohocken, PA. (Can be downloaded from www.ASTM.org or purchased by phone from ASTM Publications, 610 832 9500)
12. California Department of Health Services, *Reducing Occupant Exposure to Volatile Organic Compounds (VOCs) from Office Building Construction Materials: Non-Binding Guidelines*. Berkeley: Indoor Air Quality Section, Environmental Health Laboratory, Division of Environmental and Occupational Disease Control, California Department of Health Services.

13. DOE, *International Performance Measurement and Verification Protocol*. Washington, DC: U.S. Department of Energy. (Note: included is the final draft. Contact DOE for the official version, or consult the web site.)

14. EPA, *Building Air Quality for Building Owners and Facility Managers.* Washington: U.S. Environmental Protection Agency. (Can be downloaded from the web site or purchased from the Superintendent of Documents.)

15. European Collaborative Action, 1997. *Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations, Report No. 19*. Ispra, Italy: Joint Research Centre – Environment Institute, European Commission.

16. International Code Council, 1998. *International Mechanical Code*, Falls Church, VA: International Code Council, Inc., January 1998. 140 pages. (International Code Council, 5203 Leesburg Pike, Suite 708, Falls Church, VA 22041-3401. (Phone 703-931-4533).

17. ISIAQ, "Control of moisture problems affecting biological indoor air quality" (TF1-1996). Ottawa, Canada: International Society of Indoor Air Quality and Climate. Available from the ISIAQ Secretariat, Via Magenta, 25, 20030 Busto Garolfo, (MI) Italy. +39 331 499 371 39 331 568091 Fax +39 331 568 023.

18. Nordic Ventilation Group, 1991. "Indoor Climate Problems – Investigation and remedial measures." Nordtest Technical Report 204. Espoo, Finland: Nordtest, P. O. Box 116, FIN-02151, Espoo, Finland.

19. SMACNA, *HVAC Systems Commissioning Manual*, October, 1994. Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association, Inc., (SMACNA, 4201 Lafayette Center Drive, Chantilly, VA 22021.)

20. SMACNA, 1996. *Indoor Air Quality Guidelines for Occupied Buildings Under Construction* Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association, Inc., (SMACNA, 4201 Lafayette Center Drive, Chantilly, VA 22021.)

- ## Appendix B

Table 1 - Various recommended and adopted ventilation rates and the basis for their adoption

Minimum Ventilation Rates (cfm/person)	***Basis or Recommending/Adopting Group and Year***	***Comments***
>0.6	2% CO_2 (maximum if respiration is to be sustained)	1% on nuclear submarines resulted in higher incidence of kidney stones; therefore it was lowered to 0.5%. Jan Stolwijk, (personal communication)
>2	0.5% CO2 (TLV, OSHA)	
>7.0	0.1% CO2 (Pettenkofer Rule, 1858; body odor)	Pettenkofer looked at different rooms - a lecture hall, a restaurant, his own working room, and a school room, when people complained he measured CO_2 by trapping it in an alkaline solution, by bubbling it through. By following the respiration and perspiration of humans, he concluded that air is not good for continuous human occupancy if it had more than 0.1% carbon dioxide. The complaints were that the air was bad and that no one could occupy that space without adverse health effects. *Über den Luftwechsel in Wohngebäuden* von Dr. Max Pettenkofer. Munchen, Literaisch-Artistche anstalt der J. G. Cotta. 1858. In 1946, German ventilation standard, now revised, should not exceed 0.15%, 0.1% is the recommended maximum value. No rationale provided. German MAK value background paper, for closed, ventilated rooms, some observations of increased pressure in the head and headaches. MAK level set at 0.5%. Because these effects occur, the MAK value should not be used in offices and similar working rooms. (July 4, 1983.)
5.0	ASHRAE Standard 62-1976	Minimum value
15.0	ASHRAE Standard 62-1976	Recommended value
5.0	ASHRAE Standard 62-1981	With no smoking permitted. 2500 ppm CO_2 factor of 2 to TLV
20.0	ASHRAE Standard 62-1981	With smoking permitted
7.0	Swedish Building Code, 1980 for offices ?	0.5 ach for dwellings? Based on control of body odor using Yaglou's experimental data from the 1930's.

Minimum Ventilation Rates (cfm/person)	***Basis or Recommending/Adopting Group and Year***	***Comments***
8	Nordic Building Regulation Committee, 1981	(established to reduce energy consumption). Body odor control based on Yaglou's work. This contained room volume assumptions - valid for rooms of 12 m^3/p minimum. With higher occupant density, higher ventilation rates were required. The requirements are contained in a graph in the guideline. They also recommended 0.35 l/s m^2 in a building. The higher of the two values governed. In addition, going so low was also intended to address energy consumption considerations.
10 – 15	L. Berglund et. al.	(level below which body odors can be perceived above the background odor level of a room or school). Laboratory experimental work Stolwijk What were the criteria for these levels? Acceptability? Dissatisfaction? What percent acceptable?
16	Fanger et al (body odor).	Papers from 1987, 1988 - no more than 20% finding air unacceptable when first entering the space. *Proceedings of Indoor Air 87*, Vol 4, pp. 49 ff.. Ref. Berg-Munch et al, *Envt Intl* (1986) vol. 12, 195-199. Fanger et al, *Proc of an Engineering Foundation Conference on Management of Atmospheres in Tightly Enclosed Spaces*. ASHRAE. Atlanta, 1983, pp. 45-50.
15 – 60	ASHRAE Standard 62-1989	Based on CO_2 [650 ppm above background (outdoor air CO_2)
10 – 20	Swedish Building Code, 1988	(5 L/s-p = sedentary office work; 7 = light activity office;10 = office work: 20 = work with some smoking possibly taking place)

Minimum Ventilation Rates (cfm/person)	***Basis or Recommending/Adopting Group and Year***	***Comments***
20 – 60	Swedish Allergy Committee, 1989	(above basic continuous air flow rate of 0.5 ACH; 10 cfm/p = low emitting materials, fully checked; 15 when no pollution load or when load has not been checked; 30 when pollution load is high) We know too little about the health effects of the contaminants in indoor air. And there are so many of them present at the same time that we cannot tell the effects. Therefore it is insufficient to set values / standards for individual substances. In order to improve IAQ, it is necessary to increase the air exchange rate, so that all pollutants indoors are lowered. It is quite clear allergic individuals and other hypersensitive persons will react earlier and more pronounced to lower levels of indoor air pollution than other people. Therefore, besides a continuous airflow that corresponds to 0.5 ach, there must be a flow of 10 to 30 l/s p (20 to 60 cfm/p). In order to lower the water content of the air to less than 7 g H_2O /kg dry air required 1 ach for three winter months each year. Control of mites in test houses (12/14 negative) effective at this water level. It also was based on what was reasonably achievable as determined by practical people in the field.
20 – 40	Nordic Building Regulation Committee, 1991	(for non-dwelling buildings, low-emitting materials, no smoking = 0.7 L/m^2 + 3.5 L/s-p, though total should never be less than 7 L/s-p). Compared to 1981, the building was recognized as a much greater polluter than previously recognized. So it was decided to add the building ventilation requirements to the people ventilation requirements. The values were based on the data published by Fanger regarding the source strengths.
32 – 40	Weber et al; Cain et al (tobacco smoke annoyance)	1981, symposium on air quality and indoor air, published 1982: 33 m^3/hr p (10 l/s -p) if there are 10 p in the room. 23 m^3/hr (7 l/s p) if there are 100 p in the room. Assuming one cigarette per hour per person?
28 – 100	Fanger et al (total odor)	Various publications based on earlier work by Yaglou and more recent work by Fanger et al (1987, 1988, etc.) on odor perception by panels of trained, unadapted “visitors.”

• Appendix C - Annual cost of IAQ problems in office buildings
(Levin, H., 1994.)

Estimated annual cost of IAQ problems:

12,319,000,000 sq ft in office buildings in the United States

27,161,000 workers in offices

Average 454 sq ft gross area per worker

At an assumed cost of $20/sq ft/year or $9080 per worker/year

Area actually occupied by the worker (not the gross area per worker):

100 to 200 square feet per worker

Estimated cost of $2000 to $4000 per worker/yr.

The energy cost of office space ranges from $1 to $2/sq ft/yr.

Cost of energy per worker ~ $100 to $400/yr.

Cost to employer of office workers

$30,000 to $60,000/yr > $115 to $230/day, based on 260 work days/yr.

Cost of absenteeism

27 million office workers @ average of 4 days/yr away from work for respiratory illness

at $115 - $230/day = $460 - $920/yr per worker due to lost work time

$12.4 - $24.8 billion/yr.

Cost of non-absent worker with respiratory illness

Estimate 25% loss in productivity, 2 days/yr/worker

$57 - $115/year per worker due to reduced productivity at work

$1.5 - $3.1 billion /yr.

Annual cost of lost office worker productivity due to respiratory illness

$14 - $28 billion/yr in lost productivity due to respiratory illness in office workers

(without accounting for disruption of co-workers due to absence or low productivity).